Higgs Couplings 2019

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Book of Abstracts

Contents

Plenary / 1

Welcome

Corresponding Author: ian.shipsey@cern.ch

Plenary / 2

Higgs and the Universe

Corresponding Author: geraldine.servant@cern.ch

Plenary / 3

Higgs searches, Electroweak measurements, and B-anomalies at LHCb

Corresponding Author: william.james.barter@cern.ch

Plenary / 4

Parton distribution functions

Corresponding Author: ubiali@hep.phy.cam.ac.uk

Plenary / 5

Parton shower modelling

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Plenary / 6

PDF & parton shower modelling at ATLAS and CMS

Corresponding Author: james.ferrando@desy.de

Plenary / 7

Gluon fusion production

Corresponding Authors: bernhard.mistlberger@gmail.com, bernhard.mistlberger@cern.ch

Plenary / 8

Measurements of Higgs couplings to gauge bosons at CMS and ATLAS

Corresponding Author: piergiulio.lenzi@cern.ch

Plenary / 9

Higgs mass and width measurements at ATLAS and CMS

Corresponding Author: mingshui.chen@cern.ch

Plenary / 10

Modelling signal and background for ttH and tH measurements

Corresponding Author: marco.zaro@cern.ch

Plenary / 11

Measurements of ttH and tH production at ATLAS & CMS

Corresponding Author: ponyisi@utexas.edu

Plenary / 12

Search for four-top production at CMS & ATLAS

Corresponding Author: freya.blekman@cern.ch

Plenary / 13

Jet substructure

Corresponding Author: simone.marzani@ge.infn.it

Plenary / **14**

Higgs decays to third-generation fermions at CMS

Corresponding Author: janek.bechtel@cern.ch

Plenary / **15**

Higgs decays to third-generation fermions at ATLAS

Corresponding Author: pier.deviveiros@cern.ch

Plenary / **16**

Higgs physics from the top down

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Plenary / **17**

Higgs decays to light fermions at ATLAS

Corresponding Author: jkretz@hep.ph.liv.ac.uk

Plenary / **18**

Higgs decays to light fermions at CMS

Corresponding Author: luca.mastrolorenzo@cern.ch

Plenary / **19**

Effective field theory and Higgs physics

Corresponding Author: giampiero@to.infn.it

Plenary / **20**

A fit to Higgs and Electroweak data in the SMEFT

Corresponding Author: michael.trott@cern.ch

Plenary / **21**

A fit to Higgs and top data in the SMEFT

Corresponding Author: fabio.maltoni@cern.ch

Plenary / **22**

Perturbative corrections in the SMEFT

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Plenary / **23**

ATLAS Higgs cross section combination and EFT interpretations

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Plenary / **24**

CMS Higgs cross section combination and EFT interpretations

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Plenary / **25**

Probing CP-odd Higgs couplings

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Plenary / **26**

CP in Higgs couplings at CMS

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Plenary / **27**

CP in Higgs couplings at ATLAS

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Plenary / **28**

The Higgs potential, naturalness, & oblique corrections

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Plenary / **29**

Higgs self-couplings at ATLAS and CMS

Corresponding Author: luca.cadamuro@cern.ch

Plenary / **30**

Searches for exotic Higgs boson production at CMS and ATLAS

Corresponding Author: paul.daniel.thompson@cern.ch

Plenary / **31**

Searches for Higgs bosons in resonance decays at ATLAS and CMS

Corresponding Author: gaetano.barone@cern.ch

Plenary / **32**

Additional Higgs bosons

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Plenary / **33**

Higgs at future hadron colliders

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Plenary / **34**

Higgs at future lepton colliders

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Plenary / **35**

Detectors of the future

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Plenary / **36**

Progress with the Update of the European Strategy

Corresponding Author: keith.ellis@durham.ac.uk

Plenary / **37**

Exotic decays of SM & BSM Higgs bosons

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Plenary / **38**

Searches for exotic visible Higgs boson decays at CMS and ATLAS

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Parallel / **39**

Higgs Production at High x_F at the LHC and PQCD Predictions without Renormalization Scale or Scheme Ambiguities

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I will discuss a novel mechanism for the production of the Higgs boson in inclusive hadronic collisions, which utilizes the presence of multi-connected intrinsic heavy quarks in the proton's $|uudQ\bar{Q}>$ light-front wave function(LFWF). In these inclusive reactions, the Higgs boson acquires

the momentum of both the heavy quark and antiquark and thus carries 80\% or more of the projectile proton's momentum. This novel physics is important for Higgs dynamics since it provides new sensitivity to the Yukawa couplings of the Higgs to charm and bottom quarks.

The proton's LFWF is maximal at minimal offshellness; i.e., when the constituents have the same rapidity; i.e., $x_Q \propto \sqrt{m_Q^2 + k_{\perp Q}^2}$. Experiments at the ISR and FermiLab observed Λ_c, Λ_b, and even double-charm baryons hadroproduction at high x_F. NA3 also observed single and double J/ψ hadroproduction at high x_F and the EMC experiment at CERN measured $c(x,Q)$ at high x_{Bj}. The same intrinsic heavy quark QCD dynamics that produces the J/ψ at high x_F will produce the HIggs at high x_F.

We predict that the cross section for the inclusive production of the Standard Model Higgs coming from intrinsic bottom Fock states is of order 150 fb at LHC energies, peaking in the region of $x_F \simeq 0.9$. The corresponding cross section coming from gluon - gluon fusion is relatively negligible. New forward detectors will be required at the LHC, e.g. for detecting forward detection of four muons.
$pp \to H + X \to Z^0 Z^* + X \to (\mu^+\mu^-) + \mu^+\mu^- + X$.
We also propose a related novel mechanism for exclusive diffractive Higgs production $pp \to Hpp$ in which the Higgs boson also carries a significant fraction of the projectile proton momentum.
See: S.J. Brodsky, A.S.Goldhaber, B.Z. Kopeliovich and I. Schmidt,
"Higgs Hadroproduction at Large Feynman x,"
Nucl. Phys. B 807, 334 (2009)
[arXiv:0707.4658 [hep-ph]].
and S.J. Brodsky, B. Kopeliovich, I.Schmidt and J. Soffer,
"Diffractive Higgs production from intrinsic heavy quark flavors in the proton,"
Phys. Rev. D 73 113005 (2006)
[hep-ph/0603238].

I also will present improved pQCD predictions for Higgs boson hadroproduction at the Large Hadronic Collider by applying the Principle of Maximum Conformality (PMC), a rigorous procedure which resums the pQCD series using the renormalization group (RG), thereby eliminating the dependence of the predictions on the choice of the renormalization scheme while minimizing sensitivity to the initial choice of the renormalization scale. The PMC predictions show better agreement with the ATLAS measurements than the LHC-XS predictions which are based on conventional renormalization scale-setting.
See: S.Q. Wang, X.G. Wu, S.J. Brodsky and M. Mojaza,
"Application of the Principle of Maximum Conformality to the Hadroproduction of the Higgs Boson at the LHC,"
Phys. Rev. D 94, no. 5, 053003 (2016)
[arXiv:1605.02572 [hep-ph]].

Plenary / **40**

Searches for invisible Higgs boson decays at ATLAS and CMS

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Plenary / **41**

Higgs self-coupling sensitivity through loop corrections

Parallel / **42**

Associated pair production of charged Higgs bosons at linear collider in the Seesaw Type II model

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A search for a charged scalars can provide clean, rare, and direct indications for New Physics (NP) beyond the standard model. With the recent results at 13 TeV, we investigate the example of Seesaw mechanism, Type~II model that Higgs sector contains in addition to neutral Higgs bosons h, H and A, a simply- and doubly- charged states $H^{\pm}$ and $H^{\pm\pm}$. And so, assuming h to mimic the observed resonance $\sim$ 125 GeV; we ponder the practicality of the associated charged Higgs production through the $e^+e^- \to X \to ZH^{\pm}H^{\mp}$ and $e^+e^- \to X \to ZH^{\pm\pm}H^{\mp\mp}$ channels that could have further substantial challenges at the future International Linear Collider (ILC) experiments.
In view of that, we perform an extensive parameter scan in the lower part of the scalar mass spectrum taking into account the latest theoretical and experimental constraints. Our study in this regard shows that the production cross section can reach the level several fb in the reasonable parameter space notably for the $H^{\pm\pm}$ pairwise production, which can be a clean signal for NP.

Parallel / **43**

MHDM's and Singular Alignment

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We will talk about a novel way to avoid FCNC's at tree level in any multi-scalar extension of the Standard Model. This approach called Singular Alignment consists in taking all Yukawa matrices to be singularly aligned in flavor space. We mean by this that the Yukawa matrices are given as linear combinations of the rank 1 matrices that appear in the singular value decomposition of the mass matrix. We then discuss the application of this alignment to a 4-Higgs-doublet model in which each Higgs doublet gives mass to one of the fermion sets $\{m_t\}$, $\{m_b, m_\tau, m_c\}$, $\{m_\mu, m_s\}$, and $\{m_d, m_u, m_e\}$. The sets have the feature that within each of them the masses are similar. Our model explains the mass hierarchies of the sets by hierarchies of the vacuum expectation values of the Higgs doublets associated to them. All Yukawa couplings are therefore of order one. Neutrino masses could be generated by a type-I seesaw mechanism with PeV-scale singlet neutrinos. Finally, we provide the smoking gun for testing the realization of this model in nature.

Parallel / **44**

The Higgs width in the SMEFT

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The total and partial inclusive Higgs widths are crucial observables for the study of properties of the Higgs boson. In particular, they play a key role in global Higgs analyses within the framework of the Standard Model Effective Field Theory (SMEFT).
This talks presents the first full calculation of the Higgs width for two and four-body decays through vector currents, at leading order in the SMEFT. The calculation includes all the relevant dimension-6 operators and does not rely on the narrow width approximation, thereby allowing the inclusion of interference terms between diagrams with different mediating bosons. These contributions are found to be non-negligible, especially in the presence of photons.

This analytical result on the inclusive Higgs width can be directly used in global analyses of experimental data, without the need of a dedicated Monte Carlo simulation for each EFT coefficient.

Parallel / **45**

Asymptotic safety in gravity and Beyond the Standard Model

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Einstein gravity cannot be quantised using standard Quantum Field Theory techniques. Hence to describe gravity on quantum level either a new, special quantisation prescription should be proposed or General Relativity should be replaced by another theory which can be properly quantised. If the first option is true, then General Relativity should possess an interacting UV fixed point (as an asymptotically safe theory) and then GR becomes a fundamental Quantum Field Theory to arbitrary scales. There are many hints that indeed it is so.

On the other hand there are many proposals on how to extend the Standard Model, designed to deal with its fundamental inconsistencies. Since no new particles have been detected experimentally so far, the models which add only one more scalar particle and possibly right-chiral neutrinos are favoured. One of such models is the Conformal Standard Model.

If there are no intermediate scales between electroweak and Planck scale then these type of models supplemented with asymptotically safe gravity can be valid up to arbitrarily high energies and give a complete description of particle physics and gravitational phenomena.

This assumption restricts the mass of the second scalar particle to 300 +/-28 GeV and the mass of Higgs boson at 125 +/- few GeV. This has also impact on the multiple Higgs inflation scenarios. In my talk I will emphasise the need for precision measurements for top Yukawa mass and Higgs mass and comparison with the presented calculations.

Whats more various theories of gravity / different UV completions of Standard Model gives various predictions for the Higgs boson masses. Hence then by accurate measurements we can investigate the quantum gravity in the LHC.

Talk based on the articles: https://arxiv.org/abs/1810.08461, arXiv:1712.03778 and unpublished results in collaboration with Frederic Grabowski and prof. Krzysztof A. Meissner.

Parallel / **46**

Spotting hidden sectors with Higgs binoculars

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The discovery of the Higgs boson at the LHC has opened up the possibility for new physics to be discovered through its couplings and decays. In particular, it could serve as a portal to dark sectors by coupling to invisible particles or even dark matter. We consider 2 models where an interesting characteristic signature is that of di-Higgs production in association with missing energy. We introduce simplified models with a possible UV completion and study the limits we can place on these models by virtue of its couplings to the Higgs boson for a range of benchmark scenarios. We consider the dominant, $b\bar{b}$ decay channel of both Higgs bosons. The corresponding complex final state and large backgrounds motivates us to make use of multivariate analysis techniques to optimise our results.

Parallel / 47

Higgs interference effect at the one-loop level in the 1-Higgs-Singlet extension of the Standard Model

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A detailed study of Higgs interference effects at the one-loop level in the 1-Higgs-Singlet extension of the Standard Model (1HSM) is presented for the WW and ttbar decay modes with fully leptonic WW decay. We explore interference effects for benchmark points with a heavy Higgs mass that significantly exceeds 2mt. In the WW channel, the Higgs signal and the interfering continuum background are loop induced. In the ttbar channel, which features a tree-level background, we also calculate the interference with the one-loop background, which, due to the appearance of the absorptive part, is found to dominate the normalization and shape of di?fferential Higgs distributions and should therefore be considered in experimental analyses. The commonly used geometric average K-factor approximation is not appropriate. We calculate with massive top and bottom quarks. Our 1HSM and SM implementation in Sherpa+OpenLoops is publicly available and can be used as parton-level integrator or event generator.

Parallel / 48

Differential cross section measurements at ATLAS

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With the large pp collision dataset collected at 13 TeV, detailed measurements of Higgs boson production can be performed in decays to bosons. This talk presents measurements of differential cross sections in Higgs boson decays to two photons or to four leptons, and a comparison to state-of-the-art theory predictions.

Parallel / 49

Searches for lepton-flavor violating Higgs boson decays at ATLAS

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Several theories beyond the Standard Model predict lepton-flavor violating decays of the Higgs boson. This talk will present the results of searches for these decays based on pp collision data collected at 13 TeV.

Parallel / **50**

Treatment of theory uncertainties in Higgs boson measurements and searches at ATLAS

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As the integrated luminosity recorded by the LHC experiments increases, systematic uncertainties play an ever more important role in Higgs boson measurements and searches. Several measurements are already limited by systematic uncertainties. Among these, theory uncertainties on the signal and background modeling play an important role. This talk discusses a few examples of analyses where theory uncertainties play an important role, and shows how these uncertainties are assessed and implemented in the analyses.

Parallel / **51**

Search for di-Higgs production at 13 TeV and prospects for HL-LHC

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The latest results on production of Higgs boson pairs at 13 TeV by the ATLAS experiment are reported, including a combination of six different decay modes. Results include bbtautau, bbbb, bbgamgam, bbWW, WWWW and WWgamgam final states, and they are interpreted both in terms of sensitivity to the SM and as limits on kappa_lambda, a scaling of the triple-Higgs interaction strength. Future prospects of testing the Higgs self-couplings at the High Luminosity LHC (HL-LHC) will also be presented.

Parallel / **52**

Searches for BSM Higgs at ATLAS

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The discovery of the Higgs boson with the mass of about 125GeV completed the particle content predicted by the Standard Model. Even though this model is well established and consistent with many measurements, it is not capable to solely explain some observations. Many extensions addressing this fact introduce additional Higgs-like bosons which can be either neutral, singly-charged or even doubly-charged. Other theories suggest that the Higgs may couple to hidden-sector states that do not interact under the Standard Model gauge transformations. Models predicting exotic Higgs decays to pseudoscalars can explain the galactic center gamma-ray excess, if the additional pseudoscalar acts as the dark matter mediator. This talk presents recent ATLAS searches for decays of the 125 GeV Higgs boson to a pair of new light bosons, and searches for additional Higgs bosons. The current status of searches based on full Run2 data of the ATLAS experiment at the LHC are presented.

Parallel / 53

Constraining the Higgs boson self-coupling via indirect single-Higgs production and decay measurements

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After the discovery of the Higgs boson, one of the main targets of particle physics is the measurement of the Higgs boson couplings to fermions and vector bosons. Moreover, also of great interest is the observation of the interaction of the Higgs boson with itself, known as the Higgs boson self-coupling. The self-coupling is very loosely constrained by EWK precision measurements therefore new physics effects could induce large deviations from its SM expectation. The self-coupling can be measured directly using the Higgs boson pair production cross section, or indirectly through the measurement of the single-Higgs boson production and decays. In fact, at next-to-leading order in EW interaction the Higgs-decay partial widths and the cross sections of the main single-Higgs production processes depend on the Higgs boson self-coupling via weak loops. Moreover, changes in the Higgs boson self-coupling affect also the Higgs boson differential distribution, like the transverse momentum. In this talk, measurements of the Higgs boson self-coupling using single-Higgs production combining the data of the analyses targeting the γγ, ZZ*, WW*, ττ, bb decay channels and using both inclusive and differential information, will be presented. The results are obtained using ATLAS data corresponding to a luminosity of up to 80 fb−1.

Parallel / 54

A Search for Boosted Higgs and Other Low Mass Resonances decaying to two b-quarks with an associated jet at ATLAS

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The most common decay of the Higgs is to two b quarks, making it an invaluable tool to gain more insight into Higgs properties and any shortcomings of the Standard Model. At ATLAS, analyses looking for di-jet resonances are limited to masses above a TeV, due to the high transverse momentum (pT) requirements of ATLAS jet triggers. However, sub-TeV mass regions can be reached if the resonance is produced with a large relativistic boost provided by a radiated jet. The boost gives the decay products enough energy to pass the triggers, and makes them collimate into a single

large-radius jet with a distinct two-pronged structure, which combined with b-tagging techniques, can be used to reduce the QCD backgrounds significantly. From a physics perspective, looking for Higgs decays in association with an additional jet gives us access to Higgs boson production through gluon-gluon fusion, which at high Higgs pT can be significantly increased by the presence of BSM couplings. Furthermore, this final state can also be used to search for dark matter mediator particles which decay to two b-quarks. This talk will give the audience an overview and results of the first analysis of this kind in ATLAS, using 80 fb-1 of LHC Run-2 data.

Parallel / **55**

Measurement of the VH, $H \rightarrow b\bar{b}$ production as a function of the vector boson transverse momentum in 13 TeV pp collisions with the ATLAS detector.

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After the Higgs discovery at LHC in 2012, most of ATLAS Higgs analyses are focusing the attention on precision measurements of Higgs kinematic properties and on the search of new decay modes sensitive to physics Beyond the Standard Model (BSM). One of the most interesting channels is the Higgs boson decay into two b-quarks due to the large branching ratio (58%).

The observation of this decay at the LHC has been announced by ATLAS only recently because this channel is affected by large backgrounds arising from multi-jet production that make a real challenge to trigger and extract the signal. The best sensitivity is presently obtained by studying the associated Higgs boson production with a vector boson V (V=W or Z) decaying leptonically. The same dataset has been re-interpreted in the Simplified Template Cross-Section (STXS) framework. The STXS framework facilitates the measurement of the differential $pp \rightarrow VH$ cross section, used to extract information on the Higgs couplings and to put limits on BSM effects. In this talk an overview of the most recent results on the observation of VH production and $H \rightarrow b\bar{b}$ decay mode will be presented, together with the measurements of the VH, $H \rightarrow b\bar{b}$ production as a function of the vector boson transverse momentum.

Parallel / **56**

The status of Missing Mass Calculator for Higgs boson mass estimation in the ATLAS $H \rightarrow \tau\tau$ analysis

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The reconstruction of the Higgs boson mass represents one of the key challenges in the $H \rightarrow \tau\tau$ analysis, where instant τ-lepton decays contain non-detectable neutrinos. Precise mass reconstruction is a prerequisite for reasonable separation between the signal (alike $gg \rightarrow H \rightarrow \tau\tau$) and background (e.g. $Z \rightarrow \tau\tau$) processes. The ATLAS collaboration has developed an advanced technique for the Higgs boson mass reconstruction (Missing Mass Calculator, MMC) which proved its efficiency and resolution in Run 1 and first Run 2 analyses at the LHC. MMC relies on knowledge of the probability of the decay topology, the missing transverse energy (MET) is used as a proxy of neutrinos system momentum. For each event, mass is calculated over kinematically allowed phase space of the decay angles, and configuration with the highest probability is chosen as a final mass decision. Recent efforts addressed MMC re-tuning to the updated reconstruction of the ATLAS core software Athena.

A new, data-set independent, approach for MET resolution estimation based on MET significance has been introduced. A faster scheme for the mass estimation is also suggested. These results as well as plans for further developments are presented.

Parallel / 57

Search for heavy resonances in the H→ZZ channel with ATLAS

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This talk presents a search for an additional heavy Higgs boson decaying to a pair of SM Z bosons, covering heavy Higgs boson masses in the range between 200 GeV and 2 TeV. To maximize the sensitivity the search combines the two fully leptonic decay channels of the ZZ pair – ZZ⟶ 4l and ZZ ⟶ llνν, where l stands for a charged light lepton. The 4l channel profits from the very good resolution of the invariant mass of the 4 leptons, but its branching fraction is low. In contrast, events in the llνν channel are more abundant, but the final state is not fully reconstructable. For the llνν analysis, the transverse mass calculated from the transverse momentum of the charged lepton pair and the missing transverse energy, is used as an observable. In both channels, kinematic selections are applied and separate categories for the gluon–gluon fusion (ggF) and vector-boson fusion (VBF) production mode of the additional Higgs boson are defined. The results are interpreted as limits on the production cross section for an additional heavy Higgs boson under the narrow and large width assumption.

Parallel / 58

Test of CP invariance in vector-boson fusion production of the Higgs boson using H -> tau tau decays at the ATLAS experiment

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Violation of CP invariance is one of the Sakharov conditions needed to explain the observed baryon asymmetry in our universe. While CP violation is already realised in the Standard Model (SM) via the CKM matrix, its strength is not sufficient to explain the amount of observed baryon asymmetry. Hence, it is important to search for new sources of CP violation in the Higgs sector.

The vector-boson fusion production allows to investigate the CP structure of the Higgs-boson coupling to electroweak gauge bosons.

The ansatz considered is an Effective Field Theory, where the SM Lagrangian is augmented by CP-odd operators of mass dimension six. The magnitude of CP violation is then parametrised by a single parameter d~. Thus, any non-vanishing value of d~ directly corresponds to a violation of CP-invariance in the interaction.

The CP-odd Optimal Observable can be used to measure the value of d~. This observable is given by the ratio of the CP-odd interference term in the squared matrix element over the squared SM matrix element. It provides the highest sensitivity to determine d~ for small values of this parameter.

By performing a likelihood fit to the Optimal Observable distribution for different coupling scenarios exclusion limits can be derived.

The talk discusses the test of CP invariance in the vector-boson fusion production of the Higgs boson using H -> tau tau decays with the ATLAS detector.

Parallel / 59

Extending the search for di-higgs decaying to $b\bar{b}b\bar{b}$ in the boosted channel with the ATLAS detector

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After the discovery of the Higgs boson, new searches can now change their focus towards using it as a tool to probe both the Standard Model and new physics. One of such probes is the search for pair production of Higgs bosons. With the largest branching fraction, the $b\bar{b}b\bar{b}$ final state is one of the leading candidates to observe this process This talk will feature a search for Higgs boson pair production in the $b\bar{b}b\bar{b}$ final state with the ATLAS detector in data collected in 2015 and 2016, and focus on the main obstacles faced by the boosted channel. It will then explore new ways approach these challenges and improve the sensitivity of future searches of this process.

Parallel / 60

Exploring Higgs couplings in single top-quark production

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We advocate the use of the Matrix Element Method for the determination of the top-quark Yukawa coupling. We show the constraining power of this method at hand of the single top-quark production in association with a Higgs boson.
This process is highly sensitive to the value of the Yukawa coupling and, in contrast to many other processes, allows the direct measurement of the relative sign of the top-quark Yukawa coupling with respect to the Higgs-gauge boson coupling. Moreover, this process can also be used to investigate anomalous CP violating top-quark Yukawa couplings. To illustrate this, we adopt an effective model where the CP violation of the anomalous top-quark Yukawa coupling is parameterized with a phase. The effect of the anomalous coupling on single top-quark production in association with a Higgs boson is investigated and the Matrix Element Method is used with the NLO QCD cross section to extract the phase. It is demonstrated, that the Matrix Element Method is highly sensitive and allows for a precise determination of the top-quark Yukawa coupling.

Parallel / 61

Recursive neural tensor networks for jet classification

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The prospect of using AI to utilise a greater fraction of the data available from colliders is very alluring,
particularly for events with limited statistics, such as Higgs decays.
On the topic of jet identification there are no shortage of attempts at such,
however, the 'no free lunch' theorem is very central to use of AI.
Because of their boosted geometry, heavy highs decays can provide a particularly interesting playground for a number of tools.
General techniques may solve many problems, but they will suffer more from noise and tendency to overfit.
A technique with the right geometry for the problem will
have a hypothesis space that better matches the correct solution.
I will discuss the use of Recursive Neural Tensor Networks for
jet classification or tagging, as these networks are an
excellent match for the shape of the problem.

Parallel / 62

Mass spectrum and Higgs profile in B–L symmetric SSM

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We investigate the predictions on the mass spectrum and Higgs boson decays in the supersymmetric standard model extended by $U(1)_{B-L}$ symmetry (BLSSM). The model requires two singlet Higgs fields, which are responsible for the radiative breaking of $U(1)_{B-L}$ symmetry. It predicts degenerate right-handed neutrino masses ($1.7-2.2$ TeV) as well as the right-handed sneutrinos of mass < 4 TeV. The presence of right-handed neutrinos and sneutrinos trigger the baryon and lepton number violation processes, until they decouple from the Standard model particles. Besides, the model predicts rather heavy colored particles; $m_{\tilde{t}}$, $m_{\tilde{b}}$ > 1.5 TeV, while $m_{\tilde{\tau}} < 100$ GeV and $m_{\tilde{\chi}_1^{\pm}} > 600$ GeV. Even though the implications are similar to minimal supersymmetric standard model (MSSM), BLSSM can predict another Higgs boson lighter than 150 GeV. We find that the second Higgs boson can be degenerate with the lightest charge parity (CP)-even Higgs boson of mass about 125 GeV and contribute to the Higgs decay into two photons. In addition, it can provide an explanation for the excess in $h \to 4l$ at the mass scale ~ 145 GeV.

Parallel / 63

Prospects for Higgs boson measurements at the HL-LHC

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The High-Luminosity Large Hadron Collider (HL-LHC) is expected to deliver an integrated luminosity of up to 3000 fb-1. The very high instantaneous luminosity will lead to about 200 proton-proton collisions per bunch crossing ("pileup") superimposed to each event of interest, therefore providing extremely challenging experimental conditions. Prospects for measurements of the properties of

the standard model Higgs boson and searches for beyond the standard model Higgs bosons with the CMS experiment at the HL-LHC are presented.

Parallel / 64

ECAL trigger performance in Run 2 and improvements for Run 3

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The CMS Electromagnetic Calorimeter (ECAL) is a high resolution crystal calorimeter operating at the CERN LHC. It is responsible for the identification and precise reconstruction of electrons and photons in CMS, which were crucial in the discovery and subsequent characterization of the Higgs boson. It also contributes to the reconstruction of tau leptons, jets, and calorimeter energy sums, which are are vital components of many Higgs analyses.

The ECAL trigger system employs fast digital signal processing algorithms to precisely measure the energy and timing information of ECAL energy deposits recorded during LHC collisions. These trigger primitives are transmitted to the Level-1 trigger system at the LHC collisions rate of 40 MHz. These energy deposits are then combined with information from other CMS sub-detectors to determine whether the event should trigger the readout of the data from CMS to permanent storage.

This presentation will summarize the ECAL trigger performance achieved during LHC Run 2 (2015-2018), with specific reference to the impact on triggers relevant for Higgs signal processes. It will describe the methods that are used to provide frequent calibrations of the ECAL trigger primitives during LHC operation. These are needed to account for radiation-induced changes in crystal and photodetector response, to maintain stable trigger rates and efficiencies up to |eta|=3.0. They also minimize the spurious triggering on direct signals in the photodetectors used in the barrel region (|eta|<1.48). Both of these effects are increased relative to LHC Run 1 (2009-2012), due to the higher luminosities experienced in Run 2.

Further improvements in the energy and time reconstruction of the CMS ECAL trigger primitives are being explored for LHC Run 3 (2021-23), using additional features implemented in the on-detector readout. These are particularly focused on improving the performance at the highest instantaneous luminosities (which will reach or exceed 2x10^34 cm-2 s-1 in Run 3) and in the most forward regions of the calorimeter (|eta|>2.5), where the effects of detector aging will be the greatest. The main features of these improved algorithms will be described and preliminary estimates of the potential performance gains for Higgs physics will be given.

Parallel / 65

Searches for non-resonant HH production at CMS

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The most recent results from searches for non-resonant production of Higgs boson pairs at CMS will be presented.

Parallel / 66

Higgs to WW Run 2 results at CMS

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We present Higgs to WW results from the analysis of the Run 2 data. We show differential measurements as well as simplified template cross section results and coupling constraints.

Parallel / 67

EFT interpretation of STXS stage 1.1 measurements at CMS

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This talk will discuss an effective field theory interpretation of simplified template cross section (STXS) stage 1.1 measurements at CMS. The Higgs Effective Lagrangian (HEL) is used to parameterise our lack of knowledge of the electroweak symmetry breaking sector by extending the Standard Model Lagrangian to higher orders in momentum expansion.

The status of STXS stage 1.1 measurements at CMS will be summarized. Following this, the derivation of scaling equations, which model the dependence of each STXS bin on the HEL parameters, will be described. These equations are then used to extract constraints on such parameters, by fitting STXS stage 1.1 measurements from a combination of Higgs boson decay channels.

Parallel / 68

Measurement of ttH(bb) in proton-proton collision data at 13 TeV

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Measuring the top quark Yukawa coupling is an important test of the standard model (SM) of particle physics and the production of a Higgs boson in association with top quarks (ttH) is the only channel that allows a direct measurement of this SM parameter. This talk will focus on the measurement of ttH where the Higgs boson decays to bottom quarks. The data were collected by the CMS experiment in 2017 at a center-of-mass energy of 13 TeV. Because of the small cross section and challenging final state, sophisticated methods for signal/background rejection as well as signal extraction are required.

Parallel / 69

Search for H→tt with CMS

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A number of extensions of the SM predict additional Higgs bosons. If massive enough, they can decay to a pair of top quarks with a high branching fraction. The interference with the SM tt background results in a characteristic peak-dip structure in the mtt lineshape. This talk will present a search for

heavy additional Higgs bosons in the H⟶tt decay channel, performed with 36/fb of data collected by the CMS experiment. The analysis considers l+jets and dilepton final states and exploits the invariant mass of the tt system and angular observables. Model-independent results as well as an interpretation in the hMSSM model will be presented.

Parallel / **70**

Search for additional low-mass (m<125 GeV) Higgs bosons at CMS

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This presentation will summarize the status and latest results of the searches for additional low-mass (m<125 GeV) Higgs bosons at CMS.

Parallel / **71**

A deep neural network for the simultaneous estimation of the b jet energy correction and resolution for CMS

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An algorithm to obtain point and dispersion estimates for the energy of jets arising from bottom quarks is presented. b-jet energy regression is trained on a sample of b jets from simulated pp collisions. A multivariate regression estimator employing jet-composition information and the properties of the associated reconstructed secondary vertexes is implemented using a deep feed-forward neural network. The results of the algorithm are used to improve the experimental sensitivity of analyses that make use of b jets in the final state, such as observation of the Higgs boson decay to a bottom quark-antiquark pair.

Parallel / **72**

First CMS direct search for H(cc) at CMS - charm tagging and machine learning

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The first CMS results for direct search of the H boson decaying into charm quarks are presented. The search is based on proton-proton collisions recorded by the CMS experiment at the CERN LHC in 2016, corresponding to an integrated luminosity of 35.9 fb−1 at sqrt(s) = 13 TeV. The analysis strategy targets events in which the Higgs boson is produced in association with a W or a Z boson, exploiting two different regimes of the Higgs boson transverse momentum through the identification of dedicated event topologies. The "resolved-jet" and "merged-jet jet" topologies are aiming to identify respectively those events where the Higgs boson decay products give rise to two distinct AK4 jets and those where both the boosted charm quarks are reconstructed in a single AK15 jet. The talk, after a brief overview on the search design, is focussing on the analysis technical details, particularly in the heavy flavour tagging algorithm implied to efficiently identify jets originated from

the hadronization of charm quarks in such topologies, making use of advanced machine learning techniques.

Parallel / 73

SO(10) at the LHC

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We study and compare various Z′ models arising from SO(10), focusing in particular on the Abelian subgroup U(1)R×U(1)B-L, broken at the TeV scale to Standard Model hypercharge U(1)Y. The gauge group U(1)R×U(1)B-L, which is equivalent to the U(1)Y×U(1)χ in a different basis, is well motivated from SO(10) breaking and allows neutrino mass via the linear seesaw mechanism. Assuming supersymmetry, we first consider single step gauge unification to predict the gauge couplings, then we consider the detection and characterization prospects of the resulting Z′ at the LHC by studying its possible decay modes into di-leptons as well as into Higgs bosons. The main new result here is to analyse in detail the expected leptonic forward-backward asymmetry at the high luminosity LHC and show that it may be used to discriminate the U(1)R×U(1)B-L model from the usual B-L model based on U(1)Y×U(1)B-L.

Parallel / 74

Dark matter in the three Higgs doublet model

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In this talk we discuss the model with three Higgs doublets, focusing on the particular case in which only one doublet acquires an expected vacuum value (VEV), preserving a parity Z_N. The other two doublets do not develop a VEV and are, therefore, inert. The lightest field of the inert doublets is stable and a proper dark matter (DM) candidate. For the case of a Z_2 symmetry, we discuss the new regions of DM relic density and constrain the model using results from LHC and DM direct and indirect detection experiments, including the interesting case in which we allow a CP-violation phase in the inert sector. As in this model there are two generations of inert fields, there are decays that are not present in the model with a single inert doublet, such as the one-loop induced decay of the next-to-lightest scalar, $h \to H_1 H_2 \to H_1 H_1 f \bar{f}$, that would lead to a final state with a large missing energy and di-leptons/di-jets. We will also discuss the case of a Z_3 symmetry, wherein the special case of a highly symmetric potential there are two DM candidates. The we discuss a parameter space such that the two DM candidates contribute equally to the observed relic density, which corresponds to the case of high degeneration among the charged inert.

Parallel / **75**

Study of HγZ coupling at the ILC

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In the Standard Model, HγZ coupling is a loop induced coupling, therefore it might receive relatively large correction from BSM physics. In the SM Effective Field Theory, the measurement of HγZ coupling can provide a very useful constraint that helps the global fit, in particular the precise determination of HZZ and HWW couplings. At the ILC, there are two direct ways to study HγZ coupling: measuring the decay branching ratio of H->γZ, or measuring the production cross section of e+e- -> γH. In this talk, we will introduce the full simulation studies using these two ways, based on the detector model ILD at the ILC. Results will be given for an integrated luminosity of 2 ab-1 at ECM=250 GeV.

Parallel / **76**

Electroweak precision observables for the Higgs coupling determination at the ILC

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Very generically the same BSM physics that modifies Higgs couplings can also modify other electroweak couplings. A concrete example is given about the contact interaction operators in the Standard Model Effective Field Theory. In this respect, the electroweak precision observables (EWPOs) such as A_l (left right asymmetry in electron Z coupling) and Gam_l (partial width of Z to leptons) turn out to be very useful for the Higgs coupling determination. ILC can improve the EWPOs in at least two ways: by radiative return process or by a dedicated Z-pole running (Giga-Z option). In both ways, the beam polarizations play a very important role. This talk will give current prospects of improving the EWPOs at the ILC.

Parallel / **77**

Constraining the MSSM Higgs sector in the low tanb region

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We review recent progress in the calculation of the MSSM Higgs boson masses for low MA and tanb using the THDM as low-energy EFT. As an application of this calculation, we present two new Higgs benchmark scenarios valid in the region of low tanb. While all SUSY masses are chosen relatively heavy in the first scenario, the second scenario features light neutralinos and charginos. Both scenarios are largely compatible with recent LHC results. We also discuss their main phenomenological features relevant for future LHC searches.

Parallel / 78

Doubly Charged Higgs Search At The LHC : A Probe For The Complex Triplet Scalar Extension Of The SM

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Type-II seesaw model, a well motivated new physics scenario to address the origin of neutrino mass issues, includes an extra $SU(2)_L$ complex triplet scalar along with the SM particles. We show that this model can easily accommodate an absolutely stable vacuum until the Planck scale, however with strong limit on the exotic scalar masses and the corresponding mixing angle. We examine the model prediction at the current and future high luminosity run of the Large Hadron Collider (LHC) for the scalar masses and mixing angles fixed at such high-scale valid region. Specifically, we device the associated and pair production of the charged scalars as a new probe of the model at the LHC. We show that for a particular signal process the model can be tested with 5σ signal significance even at the present run of the LHC.
From some special angles, however, a single triplet is inadequate for consistent neutrino mass generation in the Type-II seesaw model. For example, the somewhat different mass and mixing patterns in the neutrino sector (as compared to those in the quark sector) calls for studies in neutrino mass matrix models. One class of such models consists of zero textures, having some vanishing entries in the mass matrix, thus leading to relations between mass eigenvalues and mixing angles, and ensuring better predictiveness in the neutrino sector. It has been shown, that zero textures are inconsistent with Type-II seesaw models. However, the extension of the standard model (SM) with two complex $SU(2)_L$ scalar triplets enables one to have the Type II seesaw mechanism operative consistently with texture-zero neutrino mass matrices. This framework predicts additional doubly charged, singly charged and neutral spinless states. We show that, for certain values of the model parameters, there is sufficient mass splitting between the two doubly charged states($H_1^{\pm\pm}$, $H_2^{\pm\pm}$) that allows the decay $H_1^{\pm\pm} \to H_2^{\pm\pm}h$, and thus leads to a unique signature of this scenario. We show that the final state $2\ell^{\pm}\ell^{\pm} + 4b + E_T$ arising from this mode can be observed at the high energy, high luminosity (HE-HL) run of the 14 TeV Large Hadron Collider (LHC).

Parallel / 79

Preserving physically important variables in optimal event selections

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Analyses of collider data, often assisted by modern Machine Learning methods, condense a number of observables into a few powerful discriminants for the separation of the targeted signal process from the contributing backgrounds. These discriminants are highly correlated with important physical observables; using them in the event selection thus leads to the distortion of physically relevant

distributions.
Focusing on the 0-lepton channel of the process VH -> bb, we present an alternative event selection strategy, based on adversarially trained classifiers. Our procedure exploits the discriminating power contained in many event variables, but *preserves* the distribution of the di-b-jet invariant mass and thus allows the Higgs signal strength to be extracted through a fit to this physically important variable. Compared to a cut-based approach pursued by ATLAS, this method consequently leads to a significant improvement in analysis sensitivity.

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Parallel / **80**

Double Higgs boson production at NLO

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We consider the next-to-leading order QCD corrections to Higgs boson pair production, using our recent calculation of the form factors in the high-energy limit. We compute the virtual corrections to the partonic cross section, applying Padé approximations to extend the range of validity of the high-energy expansion. This enables us to compare to the exact numerical calculation in a significant part of the phase space and allows us to extend the virtual matrix element grid, based on the exact numerical calculation, to larger values of the (partonic) transverse momentum of the Higgs boson, which is important for boosted Higgs studies. Improved predictions for hadron colliders with centre-of-mass energies of 14 TeV and 100 TeV are presented. The updated grid is made publicly available.

Parallel / **81**

Searches for exotic visible Higgs boson decays at CMS and ATLAS

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A summary of recent results of searches for exotic visible Higgs boson decays is presented. The searches are based on data recorded by the ATLAS and CMS detectors during LHC Run II data taking period at a center-of-mass energy of 13 TeV.

Parallel / **82**

Charged Higgs in MSSM and Beyond

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Charged Higgs boson ($H^{\pm}$), which exists in many Supersymmetric (SUSY)/Non-SUSY models, is one of the most important evidences for new physics beyond the Standard Model. This talk is about a numerical study over the constrained Minimal Supersymmetric Standard Model (CMSSM), next-to-MSSM (NMSSM) and U(1) extended MSSM (UMSSM). In this work, we investigate the allowed mass ranges of the charged Higgs boson and its dominant decay patterns, which might come into prominence in the near future collider experiments. We observe within our data that a wide mass range is allowed as $0.5(1) < m_{H^{\pm}} < 17$ TeV in UMSSM (NMSSM). According to results, the most leading decay channel is mostly $H^{\pm} \to tb$ such that $\mathrm{BR}(H^{\pm} \to tb) \sim 80\%$. While this mode remains dominant over the whole allowed parameter space of CMSSM, we realize some special domains in the NMSSM and UMSSM, in which $\mathrm{BR}(H^{\pm} \to tb) < 10\%$. In this context, the decay patterns of the charged Higgs can play a significant role to distinguish among the SUSY models. In addition to the tb decay mode, we find that the narrow mass scale in CMSSM allows only the decay modes for the charged Higgs boson to $\tau\nu$ ($\sim 16\%$), and their supersymmetric partners $\tilde{\tau}\tilde{\nu}$ ($\sim 13\%$). On the other hand, it is possible to realize the mode in NMSSM and UMSSM in which the charged Higgs boson decays into a chargino and neutralino pair up to about 25%. However, this decay mode requires non-universal boundary conditions within the MSSM framework to be available, since CMSSM yields $\mathrm{BR}(H^{\pm} \to \tilde{\chi}_1^0\tilde{\chi}_1^{\pm}) < 1\%$. It can also be probed in near future collider experiments through the missing energy and CP-violation measurements. Moreover, the chargino mass is realized as $m_{\tilde{\chi}_1^{\pm}} > 1$ TeV in NMSSM and UMSSM, and these solutions will be likely tested soon in collider experiments through the chargino-neutralino production.

Parallel / 83

Higgs EFT modifications of tau g−2 using LHC photon collisions

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The tau anomalous magnetic moment g−2 strikingly evades experimental measurement, but its larger mass implies greater sensitivity to new physics than the muon counterpart, which reports a longstanding 3–4 sigma tension. Interestingly, the only two dimension-6 SMEFT operators that modify tau g−2 at tree-level involve Higgs–gauge–fermion couplings. We propose a new strategy using the LHC as a photon collider, low multiplicity triggers, and recent advances in soft lepton reconstruction to open new sensitivity beyond LEP to these SMEFT operators and BSM contributions to tau g−2.

Parallel / 84

Gluon fusion into Higgs pairs at NLO QCD and the top mass scheme

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The measured properties of the particle detected seven years ago at LHC at CERN indicate that it might be the Higgs boson of the Standard model. However, the theoretical and experimental uncertainties allow associations with extended models. Therefore it is of essential importance to investigate the properties of this particle in more detail. The determination of the Higgs potential is crucial to check whether this particle causes the electroweak symmetry breaking. The self-coupling strength has to be determined to measure the Higgs potential. This can be achieved by measuring the trilinear coupling in Higgs pair production. The dominant process of Higgs pair production is the loop induced gluon fusion via a top- and bottom quark loops. In this talk I will present the calculation of the NLO QCD corrections considering the complete top mass dependence in the scope of the Standard Model. Besides the uncertainties caused by the factorisation and renormalisation scale dependence, the uncertainties due to the choice of the top mass are considered. The results of the differential cross section as well as of the full hadronic cross section will be shown.

Parallel / 85

Why additional Higgs bosons?

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I'll give a theory overview of why we might expect there to be more than one Higgs boson, and review the nature and phenomenology of the additional Higgs bosons that appear in various types of Higgs sector extensions.

Parallel / 86

Parton shower modelling

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In this talk we highlight some recent developments in parton shower Monte Carlo simulations. We give emphasis to the question of parton shower accuracy, and prospects for its improvement.

Parallel / 87

Higgs pair production at NLO QCD within a non-linear EFT implemented in POWHEG-BOX

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With Higgs boson couplings to vector bosons and heavy fermions being increasingly well-measured at the LHC, the SM Higgs potential is explored further than ever. Yet, the Higgs trilinear self-coupling is still largely unconstrained due to the small cross-section for Higgs boson pair production. I present NLO QCD corrections to Higgs pair production with the full top-quark mass dependence implemented within a non-linear EFT given by the Electroweak Chiral Lagrangian. The fixed-order calculation can be matched to a parton shower program (Herwig7 or Pythia8) in the POWHEG-BOX-V2 MC event generator.

Parallel / 88

On the experimental status of Composite Higgs Models

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We provide the status of composite Higgs(CH) models by confronting them with Run 1 and the latest Run 2 Higgs measurements from both CMS and ATLAS experiments. In these models, Higgs being a composite pseudo-Nambu Goldstone boson of the coset group has modified couplings with the SM fermions and gauge bosons, as compared to the SM Higgs boson. We consider these effect in terms of modified fermion and gauge boson couplings with the Higgs and in the generic model framework. In non-minimal CH models, extra Higgs doublet or singlet mixes with the light Higgs boson. We also study the constraints from non-linear effects in the (non-minimal) extended Higgs sector models, and calculate a bound on mixing angles and compositeness scale allowed by the Higgs data. Additionally, we study the sensitivity of Higgs data to top partner (exotic states present in these models) masses and mixing.

Parallel / 89

On the non-factorizable NNLO QCD corrections to VBF

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We investigate in detail the recently computed non-factorizable NNLO QCD corrections to vector boson fusion. In particular we do an in-depth comparison with the already known factorizable corrections. We also investigate the validity of the eikonal approximation even when no VBF cuts are applied and estimate the non-factorizable contributions to the inclusive VBF cross section.

Parallel / 90

Measuring lambda_hhh Using HH->bbbb at HL-LHC — A Feasibility Study

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A study into the feasibility of measuring the Higgs self-coupling, lambda_hhh using the high luminosity LHC is presented.

Reconstructing the variation in the di-Higgs invariant mass distribution with λ_{hhh} is essential to measuring this parameter well. Simulated signal data is used to demonstrate the challenges in doing this.

The above simulated signal data is then used in combination with additional simulated background data to present a sample analysis using a neural network to:

1. Separate signal from background, and
2. Discriminate signals corresponding to differing λ_{hhh}

This sample analysis is used to determine the significance with which a signal could be expected to be measured, and the limits which could be expected on λ_{hhh}.

Parallel / **91**

On the ambiguities of the BLM/PMC procedure for hadron collider processes

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In any calculation in perturbative Quantum Chromodynamics (QCD) a choice needs to be made for the unphysical renormalisation scale, μ_R. The Brodsky-Lepage-Mackenzie/Principle of Maximum Conformality (BLM/PMC) scale-setting procedure is one proposed method for selecting this scale and has previously been applied to a number of processes, including Higgs production. In this work we identify three ambiguities in the BLM/PMC procedure itself. Their numerical impact is studied using the example of the total cross-section for $t\bar{t}$ production through Next-to-Next-to-Leading Order in QCD. One ambiguity is the arbitrary choice of the value of the highest-order PMC scale. The numerical impact of this choice on the BLM/PMC prediction for the cross-section is found to be comparable to the impact of the choice of μ_R in the conventional scale-setting approach. Another ambiguity relates to the definitions of the other PMC scales and is similarly found to have a large impact on the cross-section.

Parallel / **92**

Search for the Higgs boson decaying to charm quarks using large-radius jets with the CMS experiment

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Studying the decay of the standard model Higgs boson to a pair of charm quarks is of vital importance as it directly probes the Yukawa coupling to second generation quarks. However, the hunt for H->cc is extremely challenging at the LHC due to large backgrounds. Recently, a search for H->cc has been performed by the CMS experiment, using advanced machine learning techniques and exploiting both the "resolved-jet" and "merged-jet" topologies. In this talk, we present the search in the merged-jet topology, which adopts a novel approach that reconstructs both quarks from the Higgs decay with a large-radius jet and exploits advanced deep learning techniques to identify H->cc decays. The use of these novel techniques significantly improves the sensitivity of the search.

93

Higgs 2020